# Forward physics : from SPS to LHC, what can we learn from air showers ?

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Since recent RHIC data and the development of new theories for small x physics, a new interest appeared for forward physics. At LHC, a correct description of multiple parton interactions will be crucial to understand all the results. On the other hand, forward particle production and multiple interactions are the key points of air shower development. That's why air shower measurements done by precise experiments like KASCADE can help to understand high energy interactions, using hadronic models which are able to reproduce both accelerator and air shower data. In the framework of the EPOS model, we will show what constraints can be fixed by air shower experiment on particle production from SPS to LHC energies.

## 1 Introduction

In this paper, we discuss how the comparison of extensive air shower (EAS) simulations based on EPOS, could provide new constraints for a model used in particle physics. EPOS is a hadronic interaction model, which does very well compared to RHIC data [1], and also other particle physic experiments (especially SPS experiments at CERN). But used in the air shower simulation program CORSIKA [2], some results where in contradiction with KASCADE data [3], while it was better for other cosmic ray experiments [4].

Due to the constrains of particle physics, air shower simulations using EPOS present a larger number of muons at ground [5]. On the other hand, the constrains given by cosmic ray experiments can compensate the lack of accelerator data in some given kinematic regions (very forward) and can be used to improve hadronic interaction models and in particular EPOS.

## 2 EPOS Model

One may consider the simple parton model to be the basis of high energy hadron-hadron interaction models, which can be seen as an exchange of a "parton ladder" between the two hadrons.

In EPOS, the term "parton ladder" is actually meant to contain two parts [6]: the hard one, as discussed above, and a soft one, which is a purely phenomenological object, parameterized in Regge pole fashion.

In additions to the parton ladder, there is another source of particle production: the two off-shell remnants. We showed in ref. [7] that this "three object picture" can solve the "multi-strange baryon problem" of conventional high energy models, see ref. [8].

Hence EPOS is a consistent quantum mechanical multiple scattering approach based on partons and strings [6], where cross sections and the particle production are calculated consistently, taking into account energy conservation in both cases (unlike other models where energy

conservation is not considered for cross section calculations[9]). Nuclear effects related to Cronin transverse momentum broadening, parton saturation, and screening have been introduced into EPOS[10]. Furthermore, high density effects leading to collective behavior in heavy ion collisions are also taken into account[11].

Energy momentum sharing and remnant treatment are the key points of the model concerning air shower simulations because they directly influence the multiplicity and the inelasticity of the model. At very high energies or high densities, the so-called non-linear effects described in[10] are particularly important for the extrapolation for EAS and it's one of the parts which has been changed in EPOS 1.99 in comparison with the previous version 1.61.

### *2.1 Cross section*

We learned from KASCADE data[3], that the energy carried by hadrons in EPOS 1.61 simulations is too low. It means than the showers are too old when they reach ground and it was due to a problem in the calculation of the nuclear cross section and to a too large remnant break-up at high energy (leading to a high inelasticity).

To improve the predictive power of the model, the effective treatment of non-linear effects describe in[10] has been made consistent to describe both proton-proton, hadron-nucleus and nucleus-nucleus data with a unique saturation scale which can be fixed thanks to proton-proton cross section and Cronin effect in dAu collisions at RHIC as shown fig. 1. Details will be published in a dedicated article.

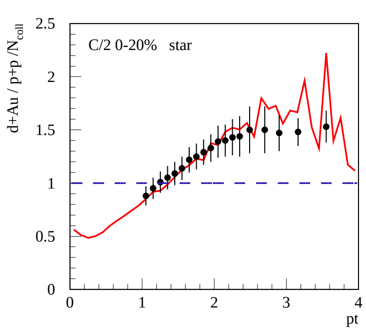


Figure 1: Ratio of the most central deuteron-gold collisions over proton-proton normalized by the Glauber number of binary collisions for the pt distribution of charged particles at 200 GeV for EPOS (line) and compared to data[12] (points)

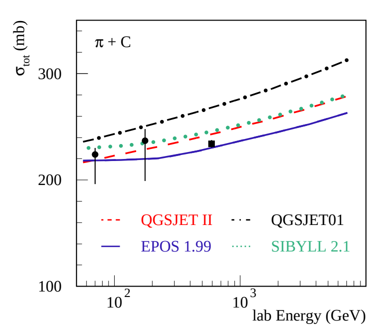


Figure 2: Total cross section of $\pi$-carbon interactions. EPOS 1.99, QGSJET II, QGSJET01 and SIBYLL 2.1 hadronic interaction models (lines) are compared to data[13] (points)

The EPOS 1.99 (full line) pion-carbon total cross section is shown Fig 2. It is now in very good agreement with the data[13] while the other hadronic interaction models used for air shower physics QGSJET01[14] (dashed-dotted line), QGSJET II[15] (dashed line) and SIBYLL[16] (dotted line) overestimate the pion-carbon cross-section for energies above 100 GeV. In fig 3, the extrapolation to proton-air data up to the highest energies is shown in comparison with measurement from cosmic ray experiments. The surface around the line for EPOS 1.99 represents the uncertainty due to the definition of the inelastic cross section as measured by cosmic ray experiments. The difference between the top and the bottom of the area is the part of the cross-section where secondary particles are produced without changing the projectile (target diffraction). So any cross section chosen in this band would give the same result in term of air shower development. Cross section of other models include this target diffraction (top of the band). In comparison with EPOS 1.61 (dashed-dotted line), the EPOS 1.99 cross section has been notably reduced.

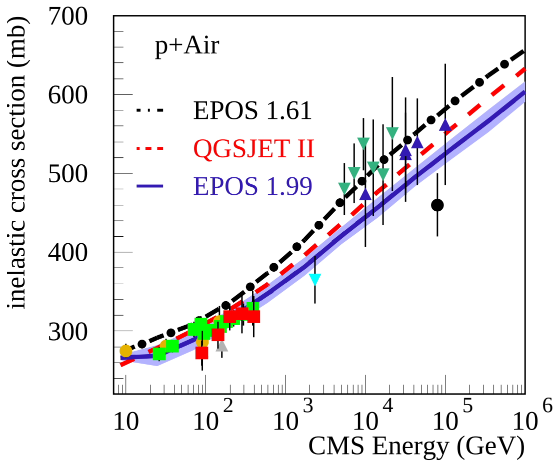


Figure 3: Inelastic cross section of proton-air interactions. EPOS 1.99, QGSJET II, and EPOS 1.61 hadronic interaction models (lines) are compared to data of air shower experiment (points).

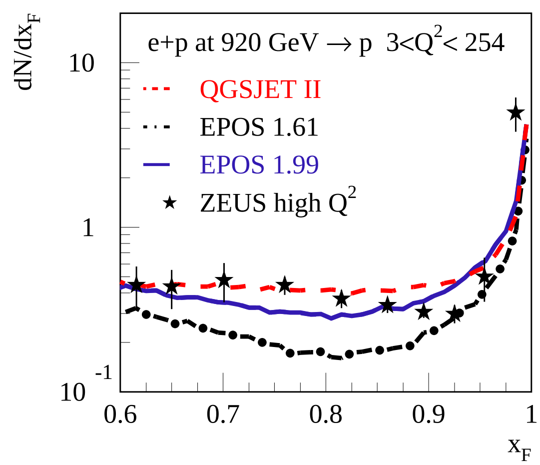


Figure 4: Proton longitudinal momentum fraction $x_L$ distribution in e-p interactions. EPOS 1.99 (full), QGSJET II (dashed), and EPOS 1.61 (dashed-dotted) models are compared to data [17] (stars).

### *2.2 Inelasticity*

As shown on fig. 4, the deficit of leading protons in EPOS 1.61 was very strong around $x_L = 0.75$. It has been corrected in EPOS 1.99. As a consequence, EPOS 1.99 has a reduced excitation probability at high energy compared to EPOS 1.61, increasing the number of protons in the forward direction and reducing the inelasticity. Used in air shower simulations, the effect of the reduced cross section and inelasticity of the new EPOS version is clearly visible on the maximum energy of hadrons at ground as shown fig. 5. The shower being younger at ground with EPOS 1.99, the maximum energy is up to 60% higher than in the previous release 1.61. The results are now close to QGSJET II results but with a different slope due to a different elongation rate.

Together with a reduced number of muons at ground due to the reduced remnant break-up [18], the results of EPOS 1.99 should be in a much better agreement with KASCADE data. Analysis is currently done by the KASCADE-Grande collaboration.

### *2.3 Multiplicity*

The air shower data indicated that EPOS 1.61 had a too large cross section and inelasticity. It has been corrected by an improved treatment of the non-linear effects and of the remnants. As a consequence, not only the results for cosmic ray experiments have been changed, but we obtain new predictions for the LHC experiments. For instance, the multiplicity distributions of charged particles for inelastic events (no cut in pseudorapidity) for proton-proton collision at LHC as plotted on fig. 6 show that EPOS 1.99 (full) has a smaller maximum multiplicity than EPOS 1.61 (dashed-dotted) but with a larger probability for events with a small multiplicity. QGSJET II (dashed), which has a much larger number of parton ladder, predicts much larger fluctuations.

## 3 Summary

EPOS is an interaction model constructed on a solid theoretical basis. It has been tested very carefully against all existing hadronic data, also those usually not considered important

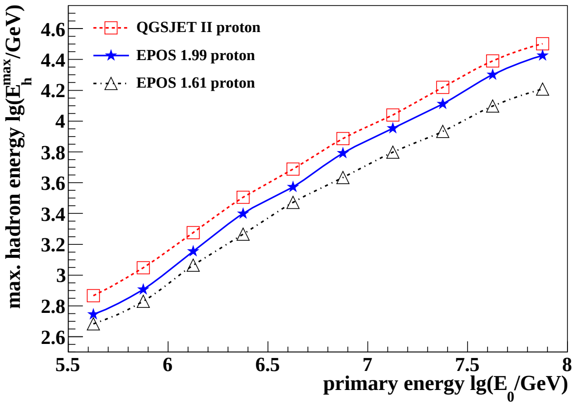


Figure 5: Maximum hadron energy as a function of the primary energy for proton induced showers using EPOS 1.99 (full line), EPOS 1.61 (dashed-dotted line) and QGSJET II (dashed line) as high energy hadronic interaction models.

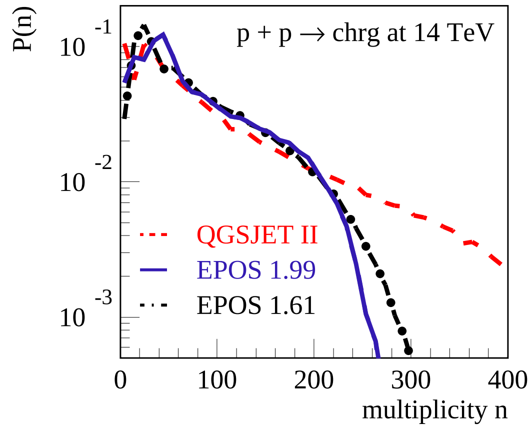


Figure 6: Multiplicity distributions of charged particles for inelastic events (no cut in pseudorapidity) for proton-proton collisions at LHC for EPOS 1.99 (full), QGSJET II (dashed), and EPOS 1.61 (dashed-dotted) hadronic interaction models.

for cosmic rays. In EAS simulations, EPOS provides more muons than other models, which was found to be linked to an increased diquark production in both string ends and string fragmentation. To solve the problems pointed out by the comparison with KASCADE data, the treatment of screening effects in nuclear collisions has been improved in EPOS. The new EPOS 1.99 has now a reduced cross section and inelasticity compared to the previous EPOS 1.61 which leads to deeper shower development in better agreement with air shower experiments. As a consequence, we could notice a none-negligible change for the LHC predictions. EPOS is a unique tool to test particle physics against both accelerator experiments and air shower experiments.

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